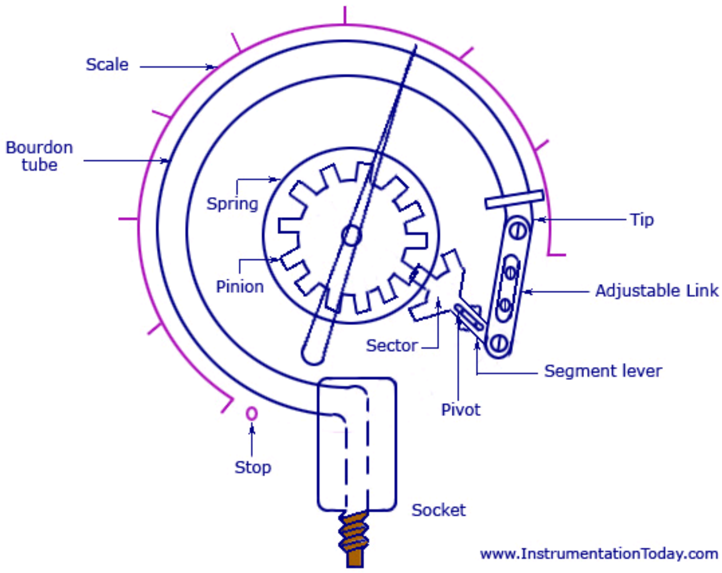
UNIT-III

BOURDON GAUGES:

Bourdon gauges are known for its very high range of differential pressure measurement in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer. The basic idea behind the device is that, cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure. The bourdon pressure gauges have a slight elliptical cross-section and the tube is generally bent into a C-shape or arc length of about 270 degrees. The detailed diagram of the bourdon tube is shown below.



Bourdon Tube Pressure Gauge

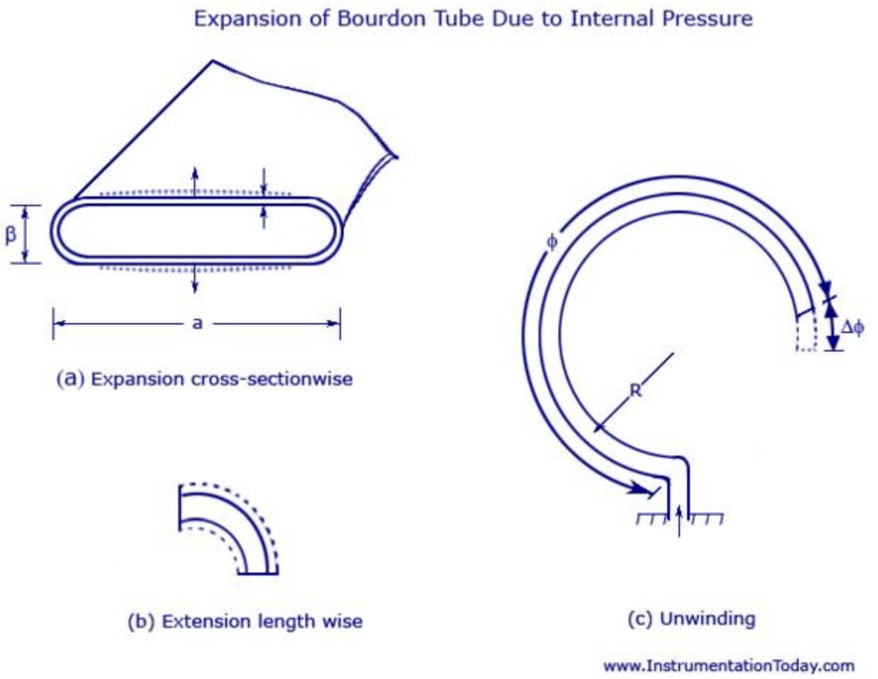
As seen in the figure, the pressure input is given to a socket which is soldered to the tube at the base. The other end or free end of the device is sealed by a tip. This tip is connected to a segmental lever through an adjustable length link. The lever length may also be adjustable. The segmental lever is suitably pivoted and the spindle holds the pointer as shown in the figure. A hair spring is sometimes used to fasten the spindle of the frame of the instrument to provide necessary tension for proper meshing of the gear teeth and thereby freeing the system from the backlash. Any error due to friction in the spindle bearings is known as lost motion. The mechanical construction has to be highly accurate in the case of a Bourdon Tube Gauge. If we consider a cross-section of the tube, its outer edge will have a larger surface than the inner portion. The tube walls will have a thickness between 0.01 and 0.05 inches.

Working

As the fluid pressure enters the bourdon tube, it tries to be reformed and because of a free tip available, this action causes the tip to travel in free space and the tube unwinds. The simultaneous actions of bending and tension due to the internal pressure make a non-linear movement of the free tip. This travel is suitable guided and amplified for the measurement of the internal pressure. But the main requirement of the device is that whenever the same pressure is applied, the movement of the tip should be the same and on withdrawal of the pressure the tip should return to the initial point.

The factors affecting the sensitivity of a Bourdon gauge

Because of the internal pressure, the near elliptic or rather the flattened section of the tube tries to expand as shown by the dotted line in the figure below (a). The same expansion lengthwise is shown in figure (b). The arrangement of the tube, however forces an expansion on the outer surface and a compression on the inner surface, thus allowing the tube to unwind. This is shown in figure (c).



Like all elastic elements a bourdon tube also has some hysteresis in a given pressure cycle. By proper choice of material and its heat treatment, this may be kept to within 0.1 and 0.5 percent of the maximum pressure cycle. Sensitivity of the tip movement of a bourdon element without restraint can be as high as 0.01 percent of full range pressure reducing to 0.1 percent with restraint at the central pivot.

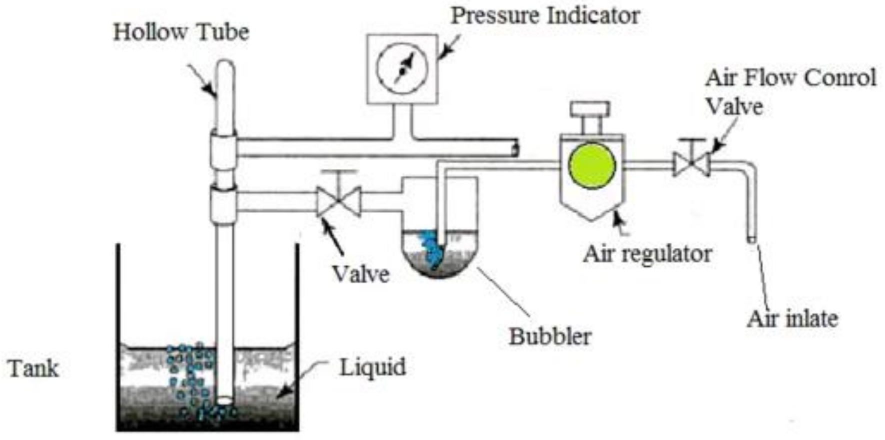
The factors that affect the sensitivity of a Bourdon gauge are radius(R) of the bourdon tube, major and minor axis length (α,β) of the tube, thickness of the tube(t), area of cross section of the tube (A), and the Young's modulus of the material (E), Coil length, Tip travel

DESIGN OF AIR PURGE SYSTEM FOR LEVEL MEASUREMENT:

Air Purge Method (Bubbler Level Measurement)

Air purge method is used for level measurement. It is also known as bubbler method. This is one of the most popular method for hydrostatic liquid level measuring system. which is suitable for any type of liquid level. The Bubbler System is an inexpensive but accurate means of measuring the fluid level in open or vented containers, especially those in harsh environments such as cooling tower sumps, swimming pools, reservoirs. The system consists of a source of compressed air, air flow restrictor, sensing tube and pressure transmitter. The only component of the Bubbler System that is exposed to the elements is the sensing tube.

Construction



It is consist of a hollow tube which is inserted in the liquid of the tank. Two connection are made with the bubbler tube one to the pressure gauge and another to the regulated air supply, calibrated in terms of liquid level. a bubbler is connected in the series with air supply line which simply as a visual check to the flow of the supply of the air. A level recorder may be connected with the pressure gauge to keep continues record of liquid level as shown in fig.

Working

When there is no liquid in the tank or the liquid in the tank is below the bottom end of the bubbler tube and the pressure gauge indicates zero. In other words, if there is no back pressure because the air escapes to the atmosphere. As the liquid level in the tank increases, the air flow is restricted by the depth of liquid and the air pressure acting against liquid head appears as back pressure to the pressure gauge.

This back pressure causes the pointer to move on a scale, calibrated in terms of liquid level. The full range of head pressure can be registered as level by keeping the air pressure fed to the tube, slightly above the maximum head in the tank. The range of the device is determined by the length of the tube. Because air is continuously bubbling from the bottom of the tube, the tank liquid does not enter the bubbler tube and hence the tube is said to be purging.

Applications

- Can be used to measure the level of the wet well to control the intake pumps.
- Can be a replacement for ultrasonic level transmitters.
- Can measure Specific Gravity.
- Can measure tank level.

Advantages

- Reliability is better than other level measurement methods
- Immune to surface foam, pH, conductivity, temperature, turbulence, and solids content.
- The sensor is not in direct contact with liquid, offering long life and greater calibration stability.
- Accuracy is good.
- The instrument panel can be located up to several hundred feet from what is being measured.
- Suitable for applications with corrosive, acidic, hazardous, volatile, molten, cryogenic, or radioactive liquids.
- The purge gas (compressed air) provides complete isolation from the measured liquid.
- Minimal Maintenance

Disadvantages

- They are not appropriate for use in non-vented vessels.
- Their calibration gets changed according to variations in density.
- Require compressed air.

Problem:1

Make use of the following specifications to build an Air purge level measurement system. Required output voltage: 0-5V; Input level range: 100cm to 700 cm; Density= $1.15gm/cm^3$

Solution:

Required output voltage: 0-5V;

Input level range: 100cm to 700 cm;

Density (ρ)= 1.15gm

Pressure at 100cm of height = 100 x (1.15/1000) = 0.115 Kg/cm^2

= 0.115 x 14.7 psi

= 1.69 psi

pressure at 700cm of height = 700 x (1.15/1000) = 0.805 Kg/cm^2

= 0.805 x 14.7 psi

= 11.9 psi

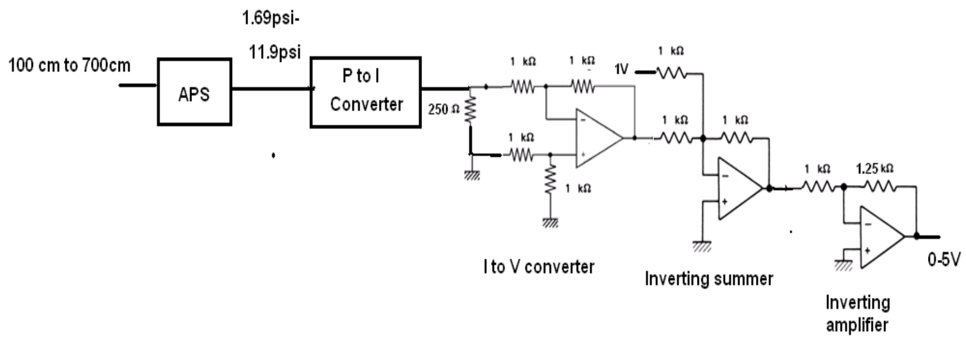
Current at particular level = 4+[(P - P_{min})/(P_{max} - P_{min})]

Current at 100cm = $4+\frac{0.115-0.115}{0.805-0.115}.16$

= 4mA

Current at 700cm = $4+\frac{0.805-0.115}{0.805-0.115}.16$

= 20mA



Problem: 2

Build an Air purge level measurement system for the following specifications. Required output voltage: 0-10V; Input level range: 15cm to 120 cm; Flowing fluid: Water with density of $1x10^{-3}$ Kg/cm^3

Solution:

Required output voltage: 0-10V; Input level range: 15cm to 120 cm;

Density (ρ) of water = 1 x 10^{-3}Kg/cm^3

Pressure at 15cm of height = 15cm x (1 x 10^{-3}Kg/cm^3) = 15 x 10^{-3}Kg/cm^2

= 15 x 10^{-3}Kg/cm^2 x 14.7 = 0.2205psi

Pressure at 120cm of height = 120cm x (1 x 10^{-3}Kg/cm^3) = 0.012 Kg/cm^2

= 0.012 x 14.7 psi

= 1.764 psi

Current at particular level = 4+[(P - P_{min})/(P_{max} - P_{min})]

Current at 100cm =

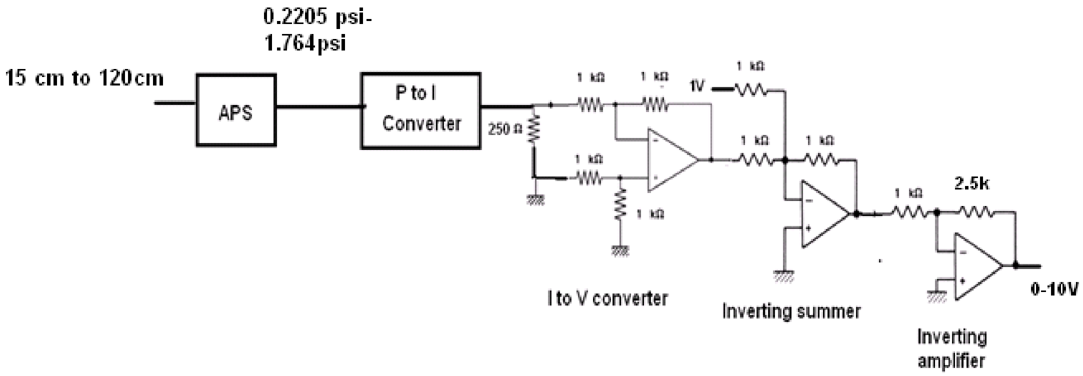
$$4+\frac{0.2205-0.2205}{1.764-0.2205}.16$$

= 4mA

Current at 700cm =

$$4+\frac{1.764-0.2205}{1.764-0.2205}.16$$

= 20mA



ELECTRONIC P+I+D CONTROLLERS

Electronic methods of realizing PID controller modes, use op amps as the primary circuit element. Discrete electronic components are also used to implement this function, and the basic principles are illustrated using op amp circuits.

Proportional Mode

Implementation of this mode requires a circuit that has a response given by

$$u_p(t) = K_p e_p(t) + u_0$$

$u(t) = K_p\, e_p(t) + u_0$

where, $u_p(t)$ = controller output in percent of full output

K_p = proportional gain

$e_p(t)$ = error in percent of variable range

u_0 = controller output with no error (or) controller bias.

Controller bias:

In a control loop, the controller bias is a constant amount of voltage or current added to or subtracted from the controller output.

$$u_p(t) = K_p e_p(t) + u(0)$$

Proportional band:

The “proportional band” of a proportional controller is the range of input signals which will cause the output signal of the controller to vary over its whole working range.

$$PB = \frac{100}{K_P}$$

If we consider both the controller output and error to be expressed in terms of voltage, the above equation can be represented by a summing amplifier. The op amp circuit shown below , is an electronic proportional controller. In this case, the electronic equation for the output voltage is

$$V_{out} = G_P V_e + V_0$$

Where,

$G_P = R_2/R_1$ = gain

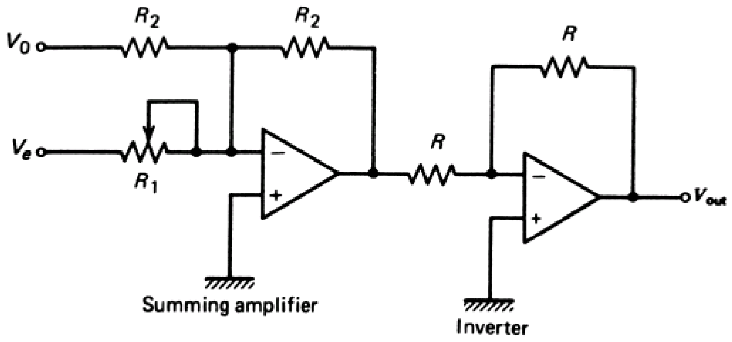
V_{out} = output voltage

V_e = error voltage

V_0 = output with zero error

And $$G_P = \frac{K_P\ \%\ of\ \ output\ range}{1\%\ of\ \ input\ range}$$

An op amp proportional-mode controller is shown below.



Characteristics of the proportional mode

1. If the error is zero, the output is a constant equal to $u(0)$
2. If there is error, for every 1% of error, a correction of percent K_P%is added to or subtracted from $u(0)$, depending on the sign of the error.
3. There is a band of error about zero of magnitude PB within which the output is not saturated at 0% or 100%.

Offset:

An important characteristic of the proportional control mode is that it produces a permanent residual error in the operating point of the controlled variable when a change in load occurs. This error is referred to as offset. It can be minimized by a larger constant, K_P , which also reduces the proportional band.

Integral Mode

The integral mode was characterized by an equation of the form

$$u_p(t) = K_I \int_0^t e_p(t)dt + u(0)$$

where, $u_p(t)$ = controller output in percent of full output

K_I = Integral gain

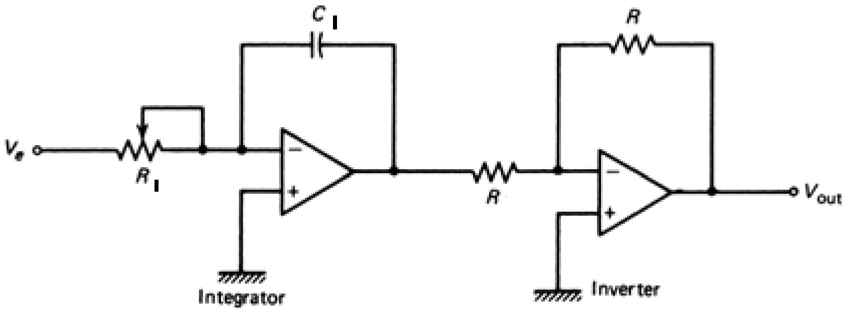
$e_P(t)$ = error in percent of variable range

$u(0)$ = controller output at t = 0

This equation can be implemented with op amps. A diagram of an integral controller is shown in the following figure. The corresponding equation relating input to output is

$$V_{out} = G_I \int_0^t V_e \, dt + V_{out}(0)$$

where
V_{out} = output voltage
$G_I = 1/RC$ = integration gain
V_e = error voltage
$V_{out}(0)$ = initial output voltage



The values of R and C can be adjusted to obtain the desired integration time. The initial controller output is the integrator output at t=0. The integration time constant determines the rate at which controller output increases when the error is constant. If it is made too large, the output rises so fast that overshoots of the optimum setting occur and cycling is produced.

Here, $G_I = \dfrac{K_I \ \% \ of \ output \ range}{1\% \ of \ error \ last \ for \ 1 \ second} = \dfrac{1}{R_I C_I}$

Characteristics of the integral mode

1. If the error is zero, the output stays fixed at a value equal to what it was when the error went to zero.

2. If the error is not zero, the output will begin to increase or decrease at a rate of K_I percent/second for every 1% of error.

Area Accumulation

The integral determines the area of the function being integrated. Thus, Equation for integral mode can be interpreted as providing a controller output equal to the net area under the error-time curve multiplied by K_I . The integral term **accumulates error** as a function of time. Thus, for every 1%-sec of accumulated error-time area, the output will be K_I percent.

Derivative Mode

The derivative mode is never used alone because it cannot provide a controller output when the error is zero.

Derivative controller mode cannot be used alone, because, in derivative control mode, the control function is proportional to change of an error in the given time. If there is no change in a process (i.e. error does not change) then the control function is zero, hence derivative controller alone cannot bring the system to its setpoint. Also the derivative controller could amplify noise.

The control mode equation can be given as,

$$u_p(t) = K_D \frac{de_p(t)}{dt}$$

where, $u_p(t)$ = controller output in percent of full output

K_D= Derivative gain

$e_p(t)$ = error in percent of variable range

This equation can be implemented with op amps. A diagram of an derivative controller is shown in the following figure.

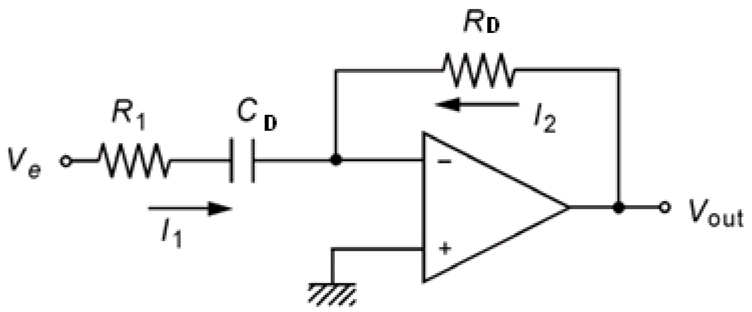
The corresponding equation relating input to output is

$$V_{out} = G_D \frac{dV_e}{dt}$$

From a practical perspective, this circuit cannot be used because it tends to be unstable. A simple modification is made by placing a resistor in series with the capacitor. The circuit exhibits a derivative response provided the following inequality is satisfied,

$$2\pi f R_1 C_D << 1$$

A practical derivative-mode op amp controller is shown below. And $G_D=R_DC_D$



Characteristics of the derivative mode

1. If the error is zero, the mode provides no output.
2. If the error is constant in time, the mode provides no output.
3. If the error is changing in time, the mode contributes an output of K_D percent for every 1%-per-second rate of change of error.
4. For direct action, a positive rate of change of error produces a positive derivative mode output.

COMPOSITE CONTROLLER MODES:

Proportional-Integral

A simple combination of the proportional and integral circuits provides the proportional-integral mode of controller action. The control mode equation can be given as,

$$u_p(t) = K_P e_p(t) + K_I \int_0^t e_p(t)dt + u(0)$$

where, $u_p(t)$ = controller output in percent of full output

K_P= proportional gain

K_I = Integral gain = K_P/τ_I

$e_p(t)$ = error in percent of variable range

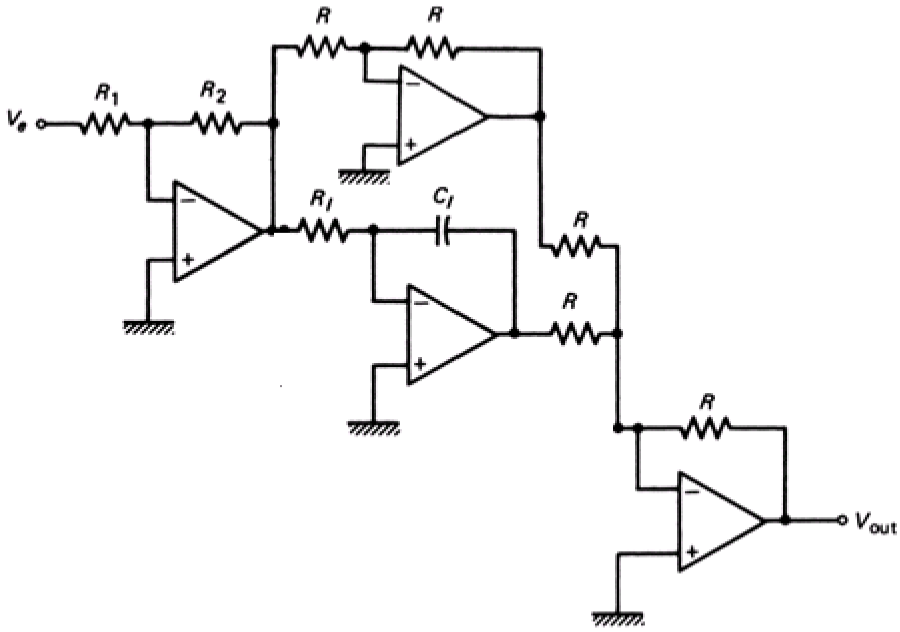
$u(0)$ = controller output at t = 0

The resulting circuit is shown below.

The definition of the proportional-integral controller mode includes the proportional gain in the integral term, so we write

$$V_{out} = \left(\frac{R_2}{R_1}\right)V_e + \left(\frac{R_2}{R_1}\right)\frac{1}{R_I C_I}\int_0^t V_e dt + V_{out}(0)$$

Proportional gain is G_p= R_2/R_1 , and the Integration gain $G_I = 1/R_I C_I$. The resulting circuit is shown in the following figure.



Proportional-Derivative

A powerful combination of controller modes is the proportional and derivative modes.

$$u_p(t) = K_P e_p(t) + K_D \frac{de_p(t)}{dt} + u(0)$$

where, $u_p(t)$ = controller output in percent of full output

K_P= proportional gain

K_D= Derivative gain = $K_P \tau_D$

$e_p(t)$ = error in percent of variable range

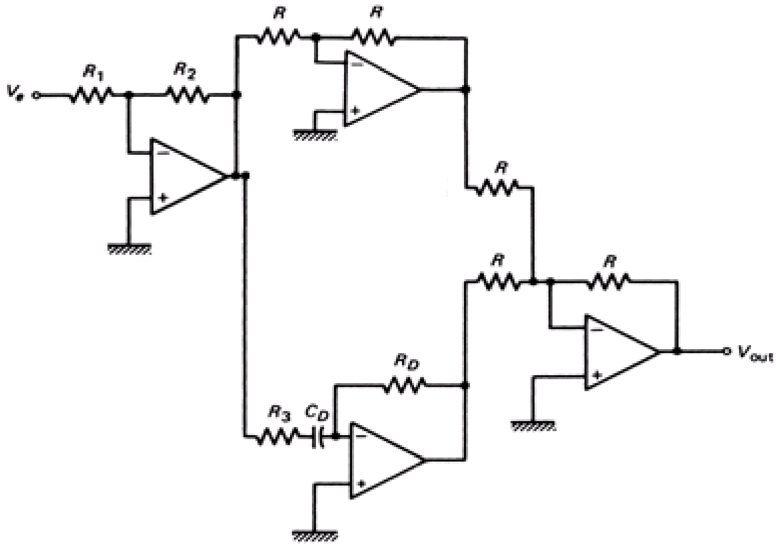
u(0) = controller output at t = 0

This combination is implemented using a circuit shown in Figure shown below. Analysis shows that this circuit responds according to the equation,

$$V_{out} = G_P V_e + G_P G_D \frac{dV_e}{dt} + V_{out}(0)$$

As $G_P = \frac{R_2}{R_1}$ and $G_D = R_D C_D$

$$V_{out} = \frac{R_2}{R_1} V_e + \left(\frac{R_2}{R_1}\right) R_D C_D \frac{dV_e}{dt} + V_{out}(0)$$



And $2\pi f_{max} R_3 C_D = 0.1$

PID (Three-Mode)

The ultimate process controller is the one that exhibits proportional, integral, and derivative response to the process-error input. This mode is characterized by the equation

$$u_p(t) = K_P e_p(t) + K_I \int_0^t e_p(t)dt + K_D \frac{de_p(t)}{dt} + u(0)$$

where, $u_p(t)$ = controller output in percent of full output

K_P= proportional gain

K_I = Integral gain = K_P/τ_I

K_D= Derivative gain = $K_D \tau_D$

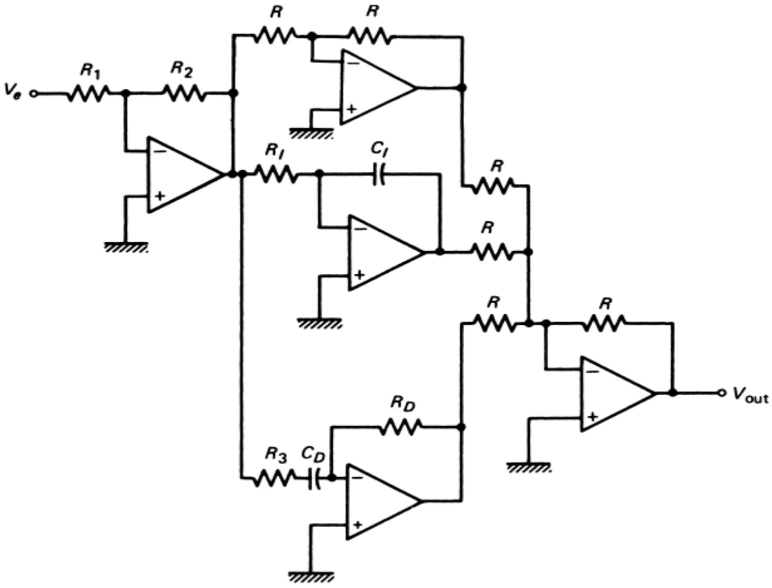
$e_p(t)$ = error in percent of variable range

u(0) = controller output at t = 0

The electronic output voltage expression is,

$$V_{out} = G_P V_e + G_P G_I \int_0^t V_e dt + G_P G_D \frac{dV_e}{dt} + V_{out}(0)$$

The Electronic citcuit for PID controller is shown below.



$$G_p = \frac{K_p \% change\ in\ output\ range}{1\% \ change\ in\ input\ range}$$

$$G_I = \frac{K_I \ \% \ \ change\ in\ output\ range}{Error \ \ of \ \ 1\% \ last \ \ for\ 1\ Second}$$

$$G_D = \frac{K_D \% change\ in\ output\ range}{Error\ change\ of \ \ 1\% \ in\ 1\ Second}$$

$$V_{out} = \left(\frac{R_2}{R_1}\right)V_e + \left(\frac{R_2}{R_1}\right)\frac{1}{R_I C_I}\int_0^t V_e dt + \left(\frac{R_2}{R_1}\right)R_D C_D \frac{dV_e}{dt} + V_{out}(0)$$

and $2\pi f_{max} R_3 C_D = 0.1$

As $G_P = \frac{R_2}{R_1}$, $G_I = \frac{1}{R_I C_I}$ and $G_D = R_D C_D$

Problem:3

Construct an Electronic Proportional – Integral controller with proportional band of 30% and an integral gain of 0.1%/(%-s) with input 0.4V to 2V and output 0-10V.

Solution:

Proportional band = 30%

K_p = 100/PB = = 100/30 = 3.33%

The input range is 0.4V to 2V and the output range is 0-10 V.

$$G_p = \frac{K_p \%change\ in\ output\ range}{1\%\ change\ in\ input\ range}$$

$$G_p = \frac{(3.33/100)(10-0)}{(1/100)(2-0.4)}$$

$= 0.333/\ 0.016 = 20.8125 = R_2/R_1$

Let $R_1 = 1\ K\Omega$, $R_2 = 20.8125 K\Omega$

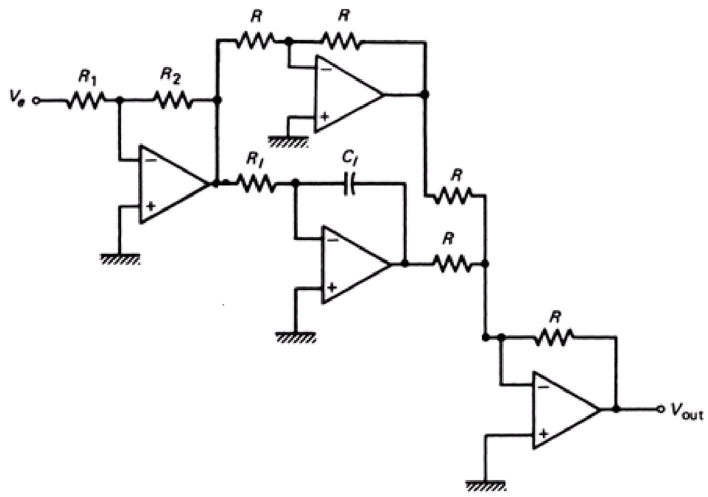
For the integral term

$$G_I = \frac{K_I\ \%\ \ change\ in\ output\ range}{Error\ \ of\ \ 1\%\ last\ \ for\ 1\ Second}$$

$$G_I = \frac{(0.1/100)(10-0)}{(1/100)(2-0.4)}$$

$= 0.01/0.016 = 0.625\ s^{-1}$

$R_I C_I = 0.625\ sec^{-1}$; Let $C_I = 1000\mu F$, $R_I = 0.625/\ 1000x10^{-6} = 625\Omega$



Problem:4

Construct a Proportional Derivative controller with K_P=2.4%/%, K_D = 0.7%/(%/min), 0-5V input and 0-10 ouput .

<u>Solution:</u>

The input range is 5 V, and the output range is 10 V.

$$G_p = \frac{K_p \%change\ in\ output\ range}{1\%\ change\ in\ input\ range}$$

$$G_p = \frac{(2.4/100)(10-0)}{(1/100)(5-0)}$$

For the proportional mode, a 1% input (error) means a voltage change of

(1/100)0.5V = 0.05V

. This should cause an output change of 2.4%

= (2.4/100) 10V = 0.24V

Gp = (0.24/0.05) = 4.8

For the derivative term

$$G_D = \frac{K_D \%change\ in\ output\ range}{Error\ change\ of\ 1\%\ in\ 1\ Second}$$

An error change of 1% per min or (0.05V/60) = 6.67 x 10^{-4}V/Sec

0.7% change in output range = (0.7/100)(10-0) = 0.07V

$$G_D = \frac{0.07}{0.05/60} = 8\ 3\ \text{Seconds}$$

These results provide the following relations:

$(R_2/R_1) = 4.8$

$R_D C_D = 83$

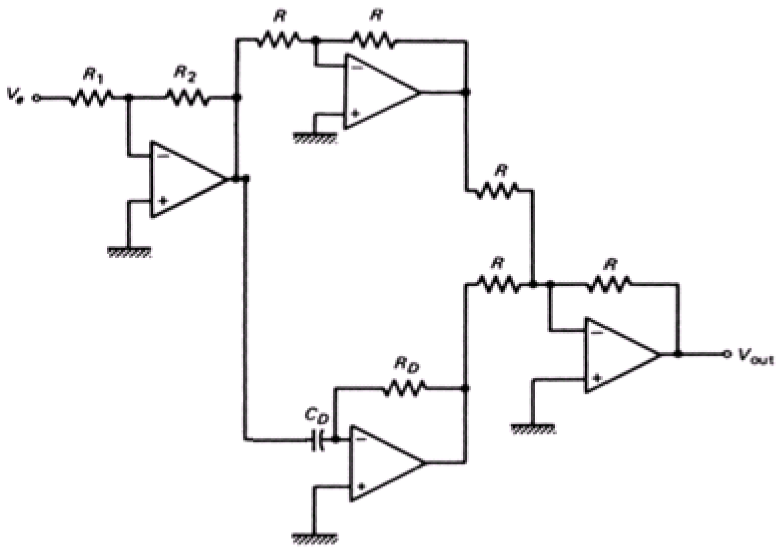
Let **R_1 = 1 k**

R_2 = 4.8 k

Let **C_D = 1000 µF ;** $R_D = 83/1000 \times 10^{-6}$

R_D = 83k

R=1k



Problem:5

A temperature control system inputs the controlled variable as a range from 0 to 4 V. The output is a heater requiring 0 to 8 V. A PID is to be used with K_P= 2.4%/%, K_I = 9%(%min), K_D = 0.7%(%min). The period of the fastest expected change is estimated to be 8sec. Develop the PID circuit.

Solution:

Proportional gain K_P = 2.4%/%

The input range is 0V to 4V and the output range is 0-8 V.

$$G_p = \frac{K_p \%change\ in\ output\ range}{1\%\ change\ in\ input\ range}$$

$$G_p = \frac{(2.4/100)(8-0)}{(1/100)(4-0)}$$

= 0.192/ 0.04 = 4.8 = R_2/R_1

Let R_1= 1 KΩ, R_2 = 4.8KΩ

For the integral term, KI=9%/min = 9/60=0.15%/sec

$$G_I = \frac{K_I\ \%\ change\ \ in\ output\ range}{Error\ of\ 1\%\ last\ for\ 1\ Second}$$

$$G_I = \frac{(0.15/100)(8-0)}{(1/100)(4-0)}$$

$$= \mathbf{0.3\ s^{-1}}$$

R_IC_I =0.3 sec^{-1} ; Let C_I = 1000μF, R_I =0.3/ 1000x10^{-6} = 300Ω

For the derivative term

$$G_D = \frac{K_D \%change\ \ in\ output\ range}{Error\ change\ of\ 1\%\ in\ 1\ Second}$$

$$G_D = \frac{((0.7*60)/100)(8-0)}{(1/100)(4-0)} = \frac{3.36}{0.04}$$ = 8 4 Seconds

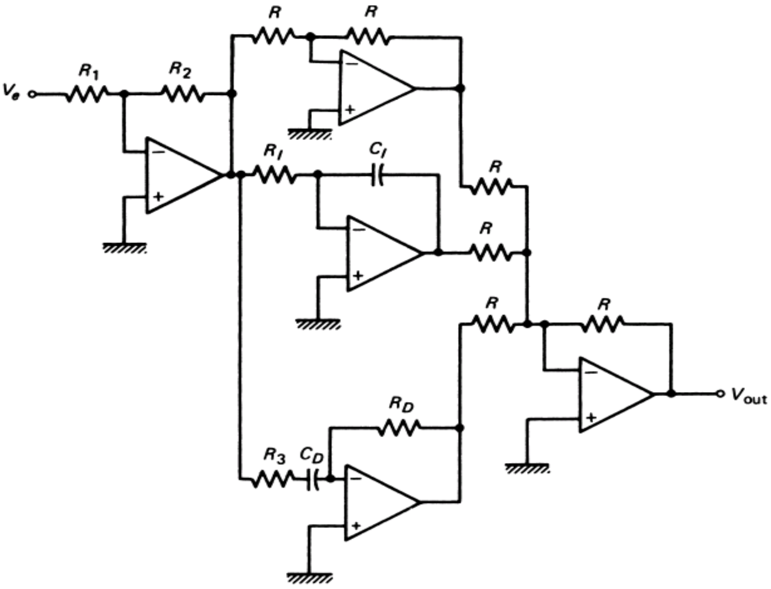
These results provide the following relations:

R_D C_D = 84 Sec

Let C_D = 1000 μF ; R_D = 84/1000 x 10^{-6}

R_D = 84k

R=1k



The period of the fastest expected change is estimated to be 8sec.

$2\pi R_3 C_D = (0.1)\ (8\ s) = 0.8$

$R_D C_D = 84$, **$C_D = 1000\ \mu F$**

$R3 = 0.8/(2\pi C_D) = 127\ \Omega$